M E M O R A N D U M

To: Jay D'Ewart
CC: Ed Vandenberg, June Wendlandt, Kimberlee Foster, Spencer Allred, Gavin Lovell, Tim Novotny, Bea Wade, John Niell, Alan Shepherd, Paul Griffin (BLM), Stefan Ekernas (USGS)
From: Bruce Lubow
Date: 30 January 2018
RE: Statistical analysis for Fall 2017 horse survey of Rock Springs area horse populations.

I. Summary Table

Survey areas and Dates:	November 8, 2017	Adobe Town HMA, Salt Wells Creek HMA
	November 9, 2017	Adobe Town HMA, Salt Wells Creek HMA
	November 10, 2017	Salt Wells Creek HMA
	November 11, 2017	Salt Wells Creek HMA, Divide Basin HMA
	November 12, 2017	Divide Basin HMA
	November 13, 2017	Divide Basin HMA
	November 14, 2017	White Mountain HMA
	November 15, 2017	Little Colorado HMA
Type of Survey	Simultaneous Double-observer	
Aviation Company	Jim Collins and Larry VanSlyke (pilots, Red Tail Aviation, Price, UT); Cessna 207, N9825M	
Agency Personnel	Kent Benson (BLM), Stefan Ekernas (USGS), Lou Arambel (Rock Springs Grazing Association), Jay D'Ewart (BLM, aviation manager)	

Table 1 (following 3 pages). Estimated population sizes (Estimate) are for the numbers of horses in the surveyed areas at the time of survey. The lower limit (LCL) and upper limit (UCL) represent the 90% confidence intervals. The coefficient of variation (CV) is a measure of precision; it is the standard error as a percentage of the estimated population. Number of horses seen (No. Seen) leads to the estimated percentage of horses that were present in the surveyed area, but that were not recorded by any observer (% Missed). The estimated number of horses associated with each HMA but located outside the HMA's boundaries or on checkerboard lands are already included in the total estimate for that HMA.

Area	Proximity to HMA	Age Class	Estimate (No. Horses)	LCL [a]	UCL	Std Err	CV	No. Horses Seen	% Missed	Estimated # of Groups	Estimated Group Size	Foals per 100 Adults	Est. No. on Solid Block[b]	Est No. on Checkerboard[b]
Adobe Town HMA	**Inside[b]**	Total	607	566	640	22	3.7%	562	7.5%	123	4.9	3.8	531	76
		Foals	22	17	25	2	11.0%	19					17	5
		Adults	585	547	618	21	3.7%	543					514	71
	Outside[b]	Total	159	133	181	14	8.7%	147	7.8%	23	6.8	1.9	131	28
		Foals	3	3	4	0	7.3%	3					1	2
		Adults	156	130	178	14	8.9%	144					130	26
	HMA Total	Total	767	715	809	26	3.4%	709	7.5%	147	5.2	3.4	662	105
		Foals	25	20	28	2	9.8%	22					18	7
		Adults	741	692	783	25	3.4%	687					644	98
Salt Wells Creek HMA	**Inside[b]**	Total	557	539	587	16	2.9%	539	3.1%	95	5.9	4.8	302	255
		Foals	26	23	29	1	5.2%	25					13	12
		Adults	531	513	559	15	2.9%	514					288	242
	Outside[b]	Total	20	17	23	2	9.8%	19	3.2%	4	4.6	0.0	5	14
		Foals	0	0	0	0	-	0					0	0
		Adults	20	17	23	2	9.8%	19					5	14
	HMA Total	Total	576	558	608	16	2.8%	558	3.1%	99	5.8	4.7	307	269
		Foals	26	23	29	1	5.2%	25					13	12
		Adults	551	532	582	16	2.9%	533					294	257
AT-SW Complex	**Complex Total**	Total	1,343					1,267	5.7%	246	5.5	4.0	969	374
		Foals	51					47					32	19
		Adults	1,292					1,220					937	354

Area	Proximity to HMA	Age Class	Estimate (No. Horses)	LCL [a]	UCL	Std Err	CV	No. Horses Seen	% Missed	Estimated # of Groups	Estimated Group Size	Foals per 100 Adults	Est. No. on Solid Block[b]	Est No. on Checkerboard[b]
White Mountain HMA	**HMA Total (all inside)**	Total	284	255	351	39	13.8%	262	7.8%	37	7.7	2.3	32	252
		Foals	7	5	10	1	22.1%	6					0	7
		Adults	278	249	343	38	13.8%	256					32	246
Little Colorado HMA	**Inside[b]**	Total	376	364	509	42	11.3%	354	5.7%	39	9.7	4.8	376	0
		Foals	17	17	23	2	9.4%	17					17	0
		Adults	358	348	486	41	11.4%	337					358	0
	Outside[b]	Total	33	21	53	8	26.0%	31	4.9%	5	6.1	0.0	33	0
		Foals	0	0	0	0	-	0					0	0
		Adults	33	21	53	8	26.0%	31					33	0
	HMA Total	Total	408	396	559	47	11.4%	385	5.7%	44	9.3	4.4	408	0
		Foals	17	17	23	2	9.4%	17					17	0
		Adults	391	377	536	45	11.6%	368					391	0
WM-LC Complex	**Complex Total**	Total	692					647	6.6%	81	8.6	3.6	440	252
		Foals	24					23					17	7
		Adults	669					624					423	246

Area	Proximity to HMA	Age Class	Estimate (No. Horses)	LCL [a]	UCL	Std Err	CV	No. Horses Seen	% Missed	Estimated # of Groups	Estimated Group Size	Foals per 100 Adults	Est. No. on Solid Block[b]	Est No. on Checkerboard[b]
Divide Basin HMA	**Inside[b]**	Total	654	637	682	14	2.2%	640	2.1%	93	7.0	5.8	422	232
		Foals	36	33	39	2	5.3%	35					21	15
		Adults	618	601	643	13	2.1%	605					400	217
	Outside[b]	Total	137	123	151	9	6.2%	132	3.9%	28	4.9	0.8	111	27
		Foals	1	1	2	0	29.7%	1					1	0
		Adults	136	122	150	8	6.2%	131					110	27
	HMA Total	Total	791	770	828	18	2.3%	772	2.4%	122	6.5	4.9	532	258
		Foals	37	34	41	2	5.2%	36					22	15
		Adults	754	735	791	17	2.2%	736					510	244
Rock Springs Region Survey (vicinity of the 5 HMAs)	**Total**	Total	2,826					2,686	5.0%	448	6.3	4.1	1,942	885
		Foals	112					106	5.3%				71	41
		Adults	2,714					2,580	5.0%				1,870	844

[a] 90% confidence interval based on percentiles of bootstrap simulation results. The lower 90% confidence interval limit (LCL) is actually less than the number of horses sighted during the survey for many estimates. This is a normal statistical result and reflects the fact that a confidence interval expresses what would likely happen if the survey were repeated. If repeated many times, some surveys would miss more horses and produce lower estimates, even after corrections, than were actually observed during this particular survey. Clearly, I conclude that there are at least as many horses as were observed during this survey, rather than using the lower confidence limit as a minimum number.

[b] Estimates for horses inside and outside of HMAs and on solid block and checkerboard lands are subsets of the estimates of total horses, not additional horses. All horses are already included in the total estimate for each HMA regardless of their location with respect to HMA boundaries (inside / outside) or ownership (solid block / checkerboard).

II. Narrative

In November of 2017, Bureau of Land Management (BLM), US Geological Survey (USGS), and Rock Springs Grazing Association (RSGA) personnel conducted simultaneous double-count aerial surveys of the wild horse populations in: Divide Basin HMA, White Mountain HMA, Little Colorado HMA, Adobe Town HMA, and Salt Wells Creek HMA (Figure 1). For management purposes White Mountain HMA and Little Colorado HMA are considered to be a complex; similarly, Adobe Town HMA and Salt Wells Creek HMA are considered to be a complex.

I analyzed these data to estimate sighting probabilities, which I then used to correct the raw counts for systematic biases (undercounts) that are known to occur in aerial wildlife surveys, and to provide confidence intervals (which are measures of uncertainty) associated with the estimated population sizes for the HMAs and surrounding areas that were surveyed (Lubow and Ransom 2016).

Overall, fall 2017 surveys followed my previous suggestions (2015 and 2016 memos) in terms of limiting the number of skilled observers, with a single front seat observer and proper seat rotation by only 2 back seat observers. These surveys were not disrupted by weather. The survey appears to have been conducted according to all recommended protocols, which I review in the Recommendations section.

After the completion of the survey, the airplane made an unplanned landing on a road, with injuries sustained by some crew members. No data collection or population estimates are worth the health of any crew member, so it is a tremendous relief that all will recover physically. This accident highlights the importance of constant awareness of the safety risks inherent to aerial surveys, and of taking all possible measures to reduce and mitigate those risks. This unfortunate incident occurred just after completion of the surveys and did not affect the validity of the data.

Population Results

The horse populations (Table 1) within these areas provided a large sample size of observations (422 horse groups, Table 2, Figure 1), of which 404 were recorded according to protocol and usable in the statistical estimation of sighting probability. Nevertheless, all of the 18 horse groups excluded from the estimation of sighting probability phase of the analysis were included in estimating horse abundance. A few observations of groups previously seen were identified (Appendix A). Some of these were used in model estimation, but none was counted twice in estimating population size. This left 415 observations to inform estimates of population size.

Average sighting probability for this survey was very high (95.0%). The high sighting probability led to excellent confidence intervals and coefficients of variation in most HMAs (Table 1). Despite the generally high sighting probabilities, precision was lower than desirable for management purposes (<10% CV) in White Mountain HMA and Little Colorado HMA due to the pilot (JC) not participating in the survey. These relatively high sighting probabilities make it unlikely that undetected biases in the estimates could still exist due to heterogeneity of sighting probabilities (but do not exclude bias due to double counting or undetected animal movements). However, greater caution is advised in interpreting the results with lower precision.

I estimate the mean size of detected horse groups, after correcting for missed groups, to be 6.3 horses/group across surveyed areas, with a median of 4.4 horses/group, and a composition of 4.1 foal horses per 100 adults at the time of these surveys. But all of these vary among areas (Table 1). These low foal ratios are likely the result of at least 2 factors: (1) these surveys followed a large-scale gather in Adobe Town HMA, Salt Wells Creek HMA, and Divide Basin HMA in which disproportionate numbers of foals were gathered; and (2) by the time of the November survey, foals are difficult to distinguish from adults from an airplane at 500 ft altitude. Consequently, these results do not accurately reflect all the foal horses born in 2017.

Sighting Probability Results

The front observers saw 68.7% of the groups (68.6% of the horses) seen by any observer, whereas the back seat observers saw 85.8% of all groups (88.6% of horses) seen (Table 2). There were undoubtedly additional groups not seen by any observer; I address this issue in the analysis that follows. These results demonstrate that simple raw counts do not fully reflect the true population without statistical corrections for missed groups, made possible by the double observer method and reported here.

The analysis method used for the surveyed areas were based on simultaneous double-observer data collected during these surveys. Informed by preliminary analyses and *a priori* reasoning, all models used in the double-observer analysis contained:

1. An estimated parameter for an intercept common to all observations.
2. A parameter in all models to account for the lower sighting probability for the front-seat observers when a group was on the pilot's side of the flight path due to the pilot's focus on flying and the obstructed view from the opposite side. This is a well-established effect and was strongly supported in preliminary analyses.
3. An additional parameter for observations on the pilot's side when the pilot was JC, who focused exclusively on flying, and was not recorded as having independently observed any horses.
4. Two individual parameters for each unique back-seat observer based on a preliminary analysis that indicated virtually no support for models with no back seat effect or only a common effect of back seat location relative to the individual effect by observer (i.e., there was very strong evidence for differences in sighting acuity among the back-seat observers).

In addition to the 5 parameters identified above that were included in all models, I tested 6 possible effects on sighting probability by fitting models for all possible combinations of these effects, resulting in 64 alternative models. The 6 effects were: (1) horse group size; (2) horse activity; (3) distance from observers to horse groups; (4) presence of one or more white horses in the group; (5) high contrast lighting; and (6) individual effects for each HMA either all included or excluded simultaneously in a given model–4 parameters (The fifth HMA, Adobe Town, was considered the baseline with none of these incremental effects).

No groups were recorded on the centerline (passing directly beneath the aircraft and not visible from the back seat), but 2 groups were recorded as seen spread across both sides of the flight path and potentially visible to back seat observers from both sides of the airplane. For these groups, sighting probability for back seat observers was estimated based on the independent probabilities of each observer spotting the group, resulting in a higher combined sighting probability.

During preliminary analyses I had also considered effects for: (1) snow cover and snow cover squared and (2) average back-seat effect. I dropped consideration of these effects due to virtually no support (<25% AICc model weight). I did not consider parameters for effects of topography or vegetation cover, or vegetation type, because conditions were too uniform to obtain sufficient data for reliable estimates of these effects.

Of the 6 effects tested in the final analysis, the effect of group size was the most strongly supported (97.8% of AIC_c model weight) followed by the individual effects of location (HMA, 83.8%). Horse movement received modest support (58.4%). The effects of white horses, lighting, and distance were weakly supported with 30.0-32.5% AICc model weight.

Visibility in the front for groups on the pilot's side was markedly lower for both pilots, as expected (Table 3), and zero for pilot JC. Pilots are expected to focus primarily on safe operation of the aircraft and may choose to observe horses when they determine that it will not interfere with flight safety. Visibility was greater for larger groups and groups closer to the flight path, also as expected. Somewhat surprisingly, visibility was lower for moving groups of horses. Although, all else being equal, a moving group should be easier to see, it is also possible that a moving group was one that had detected the approaching aircraft and was attempting to evade a perceived threat in a way that hindered visibility from the air. In other words, they may have been more visible due to motion, but less visible due to the location where they had moved to avoid detection.

Sighting probability differed between the 2 back seat observers. Observer SE had lower sighting probability, probably in part due to dividing his attention between observing and recording data. After accounting for all of the other included covariates, including the pilot effect, sighting probability was somewhat lower at White Mountain HMA compared to Adobe Town HMA, whereas it was higher than Adobe Town at the remaining 3 HMAs. It has been suggested (Jay D'Ewart Pers. Comm. 26 January 2018) that the lower sighting probability at White Mountain could be due to heavy cloud cover resulting in diminished light levels during that survey. The model covariate distinguishing flat versus high-contrast lighting might not have adequately accounted for that particularly unfavorable lighting. However, the inclusion of a unique intercept for each HMA should have at least partially accounted for this and other factors that differed among HMAs.

Correction for sighting probability resulted in a statistically estimated 5.0% of horses present in the surveyed areas not being observed, on average, although the percentage missed was as high as 7.8% at White Mountain HMA and as low as 2.4% at Divide Basin HMA. Estimated sighting probabilities for individual horse groups ranged from 25.6-99.5% for the front observers (excluding probabilities of 0.0% for horse groups on the pilot's side when JC was flying). For the back observers, estimated sighting probabilities were 42.8-99.6%, and for the combined observers 57.9-100%. Instances of lower sighting probability (<50%) for the front observers were all cases when the group was on the pilot's side. Of these, all groups with <35% sighting probability were also small (≤5 horses). Even in these survey areas with excellent sighting conditions characterized by very open and relatively smooth terrain, adjustment to raw counts for those groups not seen by any observer are needed. This underscores the importance of using a statistical method for correcting raw counts.

Assumptions and Caveats

The results obtained from these surveys are estimates of the horses present in the areas surveyed at the time of the survey and should not be used to make inferences beyond this context. The reliability of results from any population survey that is based on the simultaneous double-observer method rests on several important assumptions.

1. First, I must presume that pre-flight planning by the district specialists and USGS survey biologist led to the surveyed areas including as much as possible of the areas used by each population of horses using the surveyed HMAs. Although some fences, highways, and canyons provide deterrents to animal movement that help to contain them within the areas surveyed, these barriers are not always continuous, unbroken or impenetrable. Consequently, the numbers of animals found within the survey areas at another time could differ substantially. It is possible that temporary emigration from the surveyed areas may have contributed to some animals of a given population not being present in the surveyed areas; conversely, temporary immigration might have inflated the number present. Deterrents to

horse movement located in numerous places reduce this risk over the short time frame of the survey, but do not eliminate it. Over longer time periods, however, horses are more likely to cross barriers that are deterrents, but which may not be impenetrable throughout the year (see additional discussion in *Population Changes* section). Therefore, the estimated distribution of animals between different subareas of any complex should only be considered specific to the times of this survey; that spatial distribution almost certainly varies throughout the year.

2. Second, the simultaneous double-count method assumes that all groups of animals are flown over once during a survey period, and thus have exactly one chance to be counted by the front and back seat observers, or that groups observed more than once are identified and considered only once in the analysis. Groups counted more than once would constitute 'double counting,' which would lead to estimates that are biased higher than the true number of groups present. Additionally, groups that were never available to be seen (for example, due to temporary emigration from the study area or due to moving, undetected, from an unsurveyed area to one already surveyed) can lead to estimates that are negatively biased compared to the true population size. The results presented here are based on a survey design and methods that assume that any unobserved movements were random, so the effects would cancel each other out.

   Although attempts were made to minimize the potential for horse movement among survey days by making use of highways, rivers, and topographic barriers, inter-day horse movements during a multi-day survey could potentially bias results if those movements result in unintentional double counting or unavailability of groups. Fortunately, there were no breaks in survey due to weather. Details regarding groups that were identified as having been double-counted are presented in Appendix A.

3. Third, this method assumes that all horse groups with identical sighting covariate values have equal sighting probability. If there is additional variability in sighting probability not accounted for in the sighting models, such heterogeneity could lead to a negative bias (underestimate) of the population. This is of greater concern when sighting probabilities are lower, so this concern is minimal for the 2017 survey, although of somewhat greater concern for the Little Colorado and White Mountain HMAs.

4. A fourth assumption is that the number of horses in each group is counted accurately. In very large groups it may be common to miss a few horses unless photographs are taken and scrutinized after the flight. Group sizes ranged from 1 to 57 horses in this survey with 70 groups (17.3%) containing >10 horses (of these, 16 or 4.0% of groups had >20 horses), so inaccurate counting would have been a substantial risk for some groups had photography not been employed. Observers circled over large groups to get as accurate a count as possible and used photography to record group sizes of large groups. Using photography is in the drafted standard operating procedures for BLM double-observer aerial surveys for horses, when group size is 20 or more. Relying on raw counts made from the airplane could always lead to biased low estimates of population size.

Most of these potential sources of bias would tend to lead toward estimates that are somewhat lower, rather than higher, than the true population present during the survey. However, the risk of double counting in this survey is higher than most given the large population sizes and vast geographic areas requiring a multi-day survey period, so the estimates could be higher than the true population, even after accounting for the groups that were positively identified as having been double counted. The mostly high sighting probabilities and precision estimated for these surveys suggest that the population estimates I present here provide a sound and reliable basis for management decisions, although with greater caution advised for application of the lower precision estimates (Little Colorado and White Mountain HMAs). However, these estimates of precision do not account for unmeasurable biases resulting from any failure to meet the underlying assumptions of the methodology. Consequently, appropriate caution should be used in applying all results.

Recommendations for Future Surveys

Below, I comment on the appropriateness of the survey planning and execution with notes about improvement that have been implemented in recent years and possible additional incremental improvements to be considered in for future surveys:

1. There is a substantial benefit to maximizing the sighting probabilities and minimizing the number of different factors that cause variation in sighting probability. By far the most potent means to accomplish both objectives is to drastically limit the number of observers used and to ensure that they are well trained and highly skilled, as was done in both spring and fall 2017. Using a single pilot is also preferred. 2 pilots were used in these surveys, but sometimes on long surveys that is necessary because of pilot duty-hour limitations; however, the large sample size enabled statistical adjustment for differences between the pilots. Back seat observers must be rotated, as they were in 2017. Most important, observers should be carefully selected based on their past performance and ability to spot horses, which appears to have been the case in 2017. It is especially important to use the best possible observer in the front seat. The changes adopted in 2016 and 2017 led to a dramatic improvement in the precision and reduced the risk of undetected biases, compared with results from 2014 and especially 2015.
2. If future surveys will take place in the late fall (e.g. November) or winter, then another modification of the survey protocol that could improve average sighting probability would be to discontinue classification of foals. The extra time spent counting and recording foals distracts from observations of additional horse groups that might be missed during this activity. This survey was done late in the year when foals may be difficult to distinguish from adults, so the foal counts are probably inaccurate anyway and of little value to management. Surveys at some times of year (i.e., in August or September) are more likely to be able to identify foals, but births occur over several months, so it is difficult to time a survey when the full foal crop of the year has been born, but few are yet large enough to be mistaken for adults. I recommend that the added workload of classifying foals only be undertaken when biologists are confident that the results are likely to be an accurate representation of the annual foal crop and provide valuable information to management.
3. I emphasize the importance of using photography for large horse groups (>10 preferable, >20 is extremely important) to ensure that such groups are counted accurately. Given the tendency for horses in this area to form large groups, all future surveys should use photography so that group sizes recorded in flight can be validated with reference to photographs after the flight. In addition to using photographs to verify group size, they should also be used to identify groups that were observed twice so that these duplicate counts can be accounted for in the population estimate. Surveys should continue to use a reliable, high-resolution camera with an adequate telephoto or zoom lens for the distance between observer and horses for this purpose.
4. The pilots followed predetermined transect lines that were loaded into the pilot's GPS unit quite well during most of the fight. The flight lines were spaced at regular distances approximately 1.5 miles apart, reflecting the fact that there was little variation in topography or vegetation and sighting conditions were favorable over a majority of the survey area. The pilot followed essentially the same pattern of planned flight lines (Figure 1) as was used for these surveys in

2016 and spring 2017, though there were some improved realignments. Both pilots generally did a good job of staying close to the pre-planned transect lines and succeeded in maintaining fairly uniform spacing throughout the survey area. However, there were a few deviations, such as in the mountains between Divide Basin HMA and Little Colorado HMA, where spacing occasionally reached 2.5 miles. Spacing in mountainous terrain should probably be <1 mile and certainly not >1.5 miles. On the other hand, given the very high sighting probabilities estimated surveys of these areas in all recent years, it is apparent that the transect spacing may be closer than necessary in substantial portions of the survey area with unobstructed views. Redesigning the transects for future surveys to increase spacing in unobstructed areas (possibly to 2 miles), while reducing it in the few rugged areas (to 1 mile), could save flight time and associated costs, while improving precision and accuracy. However, if new crew members are used on the future surveys it may be beneficial to maintain the current line spacing, at least until it is demonstrated that those future crew members also have high acuity.

5. The risk of temporary migration into or out of the surveyed areas was minimized because the survey lines extended well beyond the HMA boundaries, especially where fencing, highways, and other barriers were not present, such as west of the Divide basin HMA. Compared with the 2014 and 2015 surveys, surveys in 2016 and 2017 extended survey lines for Little Colorado HMA several miles further north reaching a known fence line. Despite the low risk of temporary migrations over the time frame of the survey, the risk of migrations over longer time frames remains a concern (see *Population Changes* section, below).

6. The assumption of no movement within the survey area during the survey (potentially leading to double counting or unavailable animals) may have been violated. After the survey, BLM made efforts to identify groups that were potentially double-counted, based on group size, location, and the time between observations (Appendix A). To the extent possible, future inventories should continue to include single HMAs, and all the HMAs in any complex together, on consecutive days, in a consistent season, and using as many of the same observers across all HMAs as possible. If it is likely that a storm will disrupt a survey and the aircraft will continue to be available, it may be better to wait to begin the survey of a given HMA or complex until the storm has passed.

Population Changes

I previously reported on the April 2017 survey of these same HMAs. During the interval between the surveys, horses were gathered in 3 of the 5 HMAs. Considering the changes between the 2 surveys and the known numbers removed, I can calculate the number of new horses that would have to have been added to the population (Table 4) to obtain the results presented here. In Adobe Town, the gain was 25.7% of the spring adult population and in Little Colorado it was 21.8%. Recruitment of foals is often thought to be around 20% of the adult population, so these implied increases might be fully explained by internal fecundity.

The ratios of foals to adults captured in the fall 2017 gathers at Adobe Town HMA, Salt Wells HMA, and Divide Basin HMA is consistent with an even higher annual growth rate. The ratio of gathered foals to gathered adults at Adobe Town HMA was 25.7%; at Salt Wells HMA it was 27%; and at Divide Basin HMA it was 24.5% (Table 4). Similar foal to adult ratios were also recorded in the 2014 gather (Paul Griffin, BLM, personal communication). If foal overwinter survival rates are high, then these high ratios indicate the possibility that the region supports very high annual growth rates. It may be prudent for the BLM to plan on 25% per year as being a more typical annual growth rate in these HMAs.

However, even factoring in a 25% annual growth rate with respect to adults present in the spring, the increases at Salt Wells Creek (53.5%) and Divide Basin (61.7%) far exceed the numbers that could plausibly be explained by internal recruitment alone. Conversely, growth at White Mountain HMA was implausibly low (5.2%). Even if net migration from White Mountain HMA to Divide Basin HMA could explain some of the discrepancy, the net increase at these 2 HMAs, combined, would still be too great (46.6%) to be exclusively due to recruitment in those 2 HMAs.

I suggest that the most likely explanation for these results is net migration from outside the surveyed HMAs. Divide Basin HMA is near or adjacent to multiple HMAs in the Red Desert complex to the east. Although fencing exists in the area, gates are often left open to allow migration of mule deer and pronghorn. Migration into Salt Wells Creek HMA is possible from the south, specifically from the Sand Wash Basin HMA in Colorado; several relatively unobstructed pathways between these HMAs exist. A few horse groups were observed in the region between them during the survey, supporting the hypothesis that this corridor could be used. The small numbers found within this corridor at the time of the survey do not refute the hypothesis — it is plausible that horses may use the corridor to move from Sand Wash Basin HMA to Salt Wells Creek HMA without lingering in the corridor area. Additionally, migrations through this corridor may be more common at other times of the year. It is also possible that a few large groups migrate sporadically during a year, but that they are only located within the corridor for a few days and the 2 days on which surveys were done in 2017 did not happen to coincide with one of the significant movements.

Obstacles likely reduce the occurrence of migration between some HMAs within the survey area. For example, White Mountain and Divide Basin HMAs are separated by fencing along a highway (US191). While this is likely to minimize migrations over shorter periods, horses are capable of crossing these barriers and may do so occasionally over periods of several months if sufficiently motivated to find more abundant forage, water or other resources.

An alternative explanation – that errors in the estimates might explain the discrepancies – is not supported by the available evidence. To produce these results, the spring 2017 estimate would have to have been too low and/or the fall estimate too high. However, even assuming the upper 90% CI value for spring and the lower 90% CI value for fall produces an estimated gain for Divide Basin of 384 horses, which is still far in excess of plausible natural recruitment. Larger errors than the statistical estimates could explain a single pair of survey results like these, but we would expect the implied population growth to alternate between excessively high estimates of recruitment followed by excessively low estimates. This has not been the case over the 15-year period these surveys have been conducted by current methods – the estimated recruitment has been predominantly higher than expected or likely due to natural recruitment alone. Furthermore, there is no indication that the survey methods have failed in any systematic way. In addition, the spring 2017 and fall 2017 surveys were conducted nearly identically and by the same crew.

I conclude that immigration into these HMAs is a major contributor to population growth. Unfortunately, definitive confirmation of this hypothesis would best be obtained by means of a large-scale study involving marking numerous horses over vast areas to measure migration patterns directly. Although a less direct and conclusive test, simultaneous surveys of the plausible sources of immigrant horses (e.g., Sand Wash Basin HMA, Red Desert complex and nearby area) could provide supporting evidence of complimentary population losses in these areas.

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Appendix A. Duplicate observations.

Based on a though review of the data by Jay D'Ewart and Paul Griffin (BLM, Personal communication), the following decisions were made about excluding from the final analysis certain repeated observations of identifiable groups:

- Salt Wells HMA. Observation at waypoint 209 repeated observation at waypoint 197. Waypoint 209 had 8 adults / 4 foals on November 11th. Waypoint 197 on Nov 10th had 7 adults / 3 foals, but there were also other horses nearby at waypoints 195 and 196. The distance was 0.4 miles, the time difference was on the next day. Animals from waypoint 209 were not used in population estimates.

- Divide Basin HMA. Observation at waypoint 277 repeated observations at waypoint 269 and 270. Waypoint 277 had 20 adults and 5 foals. Waypoints 269 and 270 together had 24 adults and 4 foals. The distance was 0.25 miles and the time difference was 15 minutes. Animals from waypoint 277 were not used in population estimates.

- Divide Basin HMA. Observation at waypoint 306 repeated observation at waypoint 301. Observations at both waypoints had 12 adults. The distance was a half mile and the time difference was 16 minutes. Animals from waypoint 306 were not used in population estimates.

- Divide Basin HMA. Observation at waypoint 318 and 319 repeated observations at waypoint 263 (and maybe 264). Observations at waypoint 318 had 21 adults. Observations at waypoint 319 had 10 adults. Observation at waypoint 263 had 39 adults, with another 2 adults at waypoint 264. The distance was less than one mile and the time difference was the next day. Aircrew noted on their data forms that observed animals at waypoint 318 and 319 were repeat observations from the previous day. Animals from waypoints 318 and 319 were not used in population estimates.

- Divide Basin HMA. Observation at waypoint 329 repeated observation at waypoint 256. Observations at both waypoints had exactly 13 adults. The distance was 3.2 mi but the time difference was next day. Animals from waypoint 329 were not used in population estimates.

Table 2. Tally of raw counts of horses and horse groups by observer (front and back) and survey year for combined HMAs. This table is based on raw counts (not statistical estimates) and, therefore does not address groups not seen by any observer.

Observer	Groups Seen (Raw Count)	Horses Seen (Raw Count)	Actual Sighting Rate[a] (groups)	Actual Sighting Rate[a] (Horses)
Front	285	1,842	68.7%	68.6%
Back	356	2,372	85.8%	88.3%
Both	226	1,528	54.5%	56.9%
Combined	415	2,686		

[a] Percentage of all groups seen that were seen by each observer.

Table 3. Effect of observers and sighting condition covariates on estimated sighting probability of horse groups for both front and rear observers. Baseline case (**bold**) is for observers in the indicated seat computed for groups not on pilot's side, at Adobe Town, with no activity, group size = 4 horses (the median value, rounded), distance 0-1/4 miles (the most common value), and for observer LA in the back. Other cases vary a covariate, one effect at a time, as indicated. Sighting probabilities for each row should be compared to the baseline (first row) to see the effect of the change in observer or condition. Baseline values are shown in bold wherever they occur. Sighting probabilities are calculated from weighted averaged model parameters across all 64 models.

	Sighting Probability, Front Observer	Sighting Probability, Back Observer	Sighting Probability, Combined Observers
Baseline	**87.3%**	**88.4%**	**98.5%**
Effect of group size (N=1)	85.0%	86.2%	97.9%
Effect of active group	82.5%	83.8%	97.2%
Effect of distance (0.75 miles)	86.8%	87.8%	98.4%
Effect of white horse	88.1%	89.1%	98.7%
Effect of high contrast lighting	88.0%	89.0%	98.7%
Effect of Salt Wells Creek	92.2%	92.8%	99.4%
Effect of Divide Basin	93.8%	94.3%	99.6%
Effect of White Mountain	84.0%	85.3%	97.7%
Effect of Little Colorado	90.2%	91.0%	99.1%
Effect of Pilot's Side	35.9%	**88.4%**	92.5%
Effect of JC on Pilot's side	0.0%	**88.4%**	88.4%
Effect of observer SE in back	**87.3%**	58.4%	94.7%

[a] Sighting probability for the front observers acting as a team when the horses were on the pilot's side of the flight path, regardless of which of the front observers saw the horses first.

Table 4. Population estimates, numbers gathered, and inferred population growth for Rock Springs region Horse Management Areas in 2017.

	Spring 2017			Expected Recruitment[a]	Implied Recruitment[b]		2017 Gather			Fall 2017		
HMA	**Adults**	**Foals**	**TOTAL**	**25%**	**No.**	**%**	**Adults**	**Foals**	**TOTAL**	**Adults**	**Foals**	**TOTAL**
Adobe Town HMA	1123	29	1152	281	289	25.7%	513	132	645	741	25	767
Salt Wells HMA	976	21	997	244	522	53.5%	725	197	922	551	26	576
Complex	2099	50	2149	525	811	38.6%	1238	329	1567	1292	51	1343
Divide Basin HMA	737	31	768	184	455	61.7%	322	79	401	754	37	791
White Mountain HMA	270	8	278	68	14	5.2%	0	0	0	278	7	284
Sum (DB + WM)	1007	39	1046	252	469	46.6%	322	79	401	1032	43	1075
Little Colorado HMA	335	10	345	84	73	21.8%	0	0	0	391	17	408

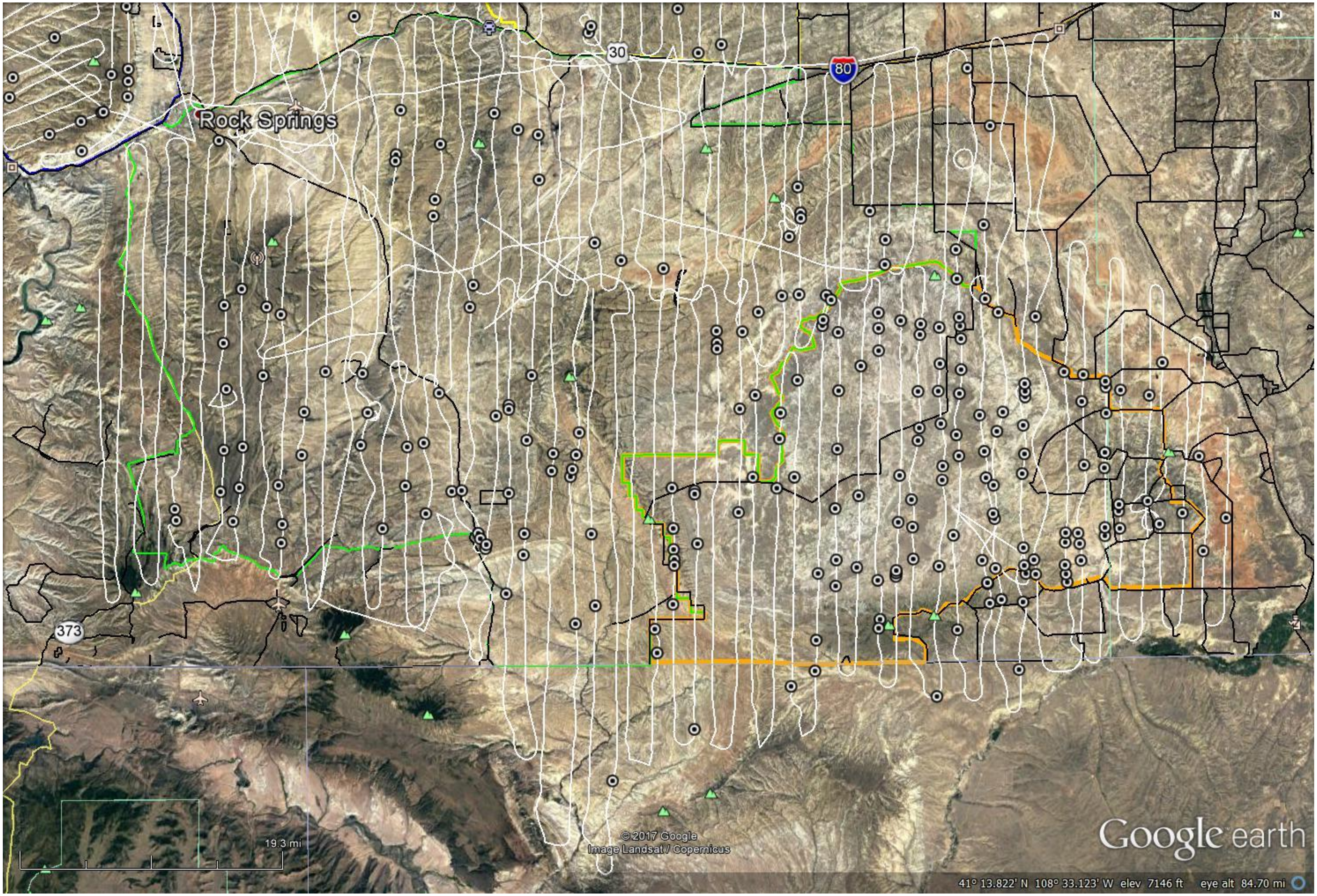
[a] Expected recruitment is the number of foals that would have been expected to be produced by the number of adults estimated to be present in Spring 2017, based on a 25% annual growth rate per adult.

[b] Implied recruitment is the number of horses that would have to be added to the spring population, accounting for the known numbers of animals gathered in fall 2017, to obtain the estimated fall population from the fall aerial surveys. This is also expressed as a percentage of the spring adult population. For example, at Adobe Town HMA, 1123 spring adults plus 25% expected recruitment of 280 foals should lead to 1123+280=1403 total animals. 645 were removed in the gather, so the expected number of remaining animals should have been 1403-645=758. Instead, the fall 2017 estimated number of animals was 767…9 more animals than what would have been expected from a 25% growth rate alone. The implied recruitment was 9 greater than the expected recruitment, or 280+9=289. As a fraction of the number of adults, the implied recruitment was 289/1123 = 25.7%.

Figure 1A (following pages)**.** Map of November 8-15, 2017 survey of Adobe Town HMA (orange) and Salt Wells Creek HMA (green). Circles are GPS waypoints at the locations where observers saw groups of animals. Black lines are fences.

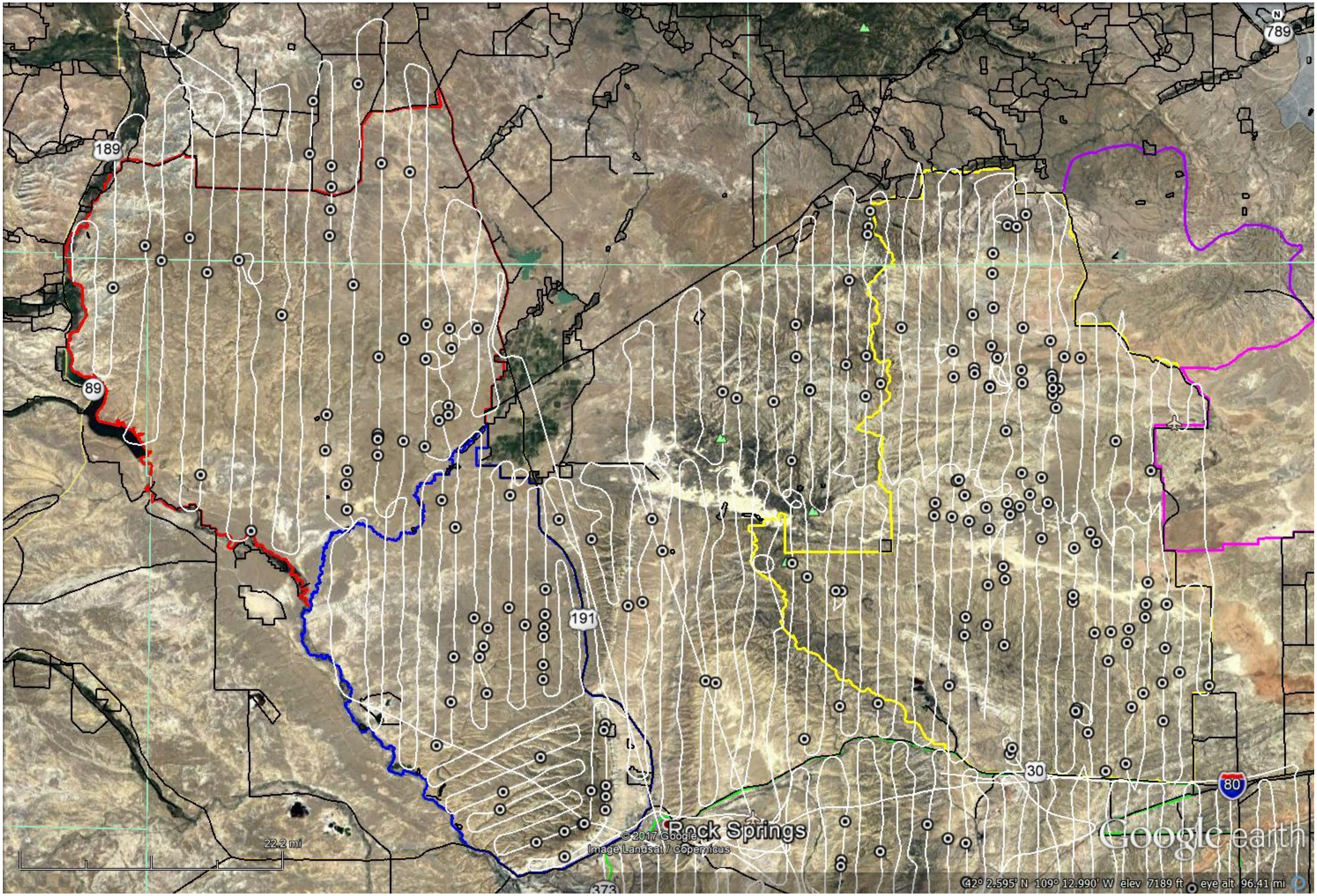
Figure 1B (following pages)**.** Map of November 8-15, 2017 survey in Divide Basin HMA (yellow), Little Colorado HMA (red), and White Mountain HMA (blue) and GPS recordings of actual flight paths (white lines). Circles are GPS waypoints at the locations where observers saw groups of animals. Black lines are fences. Adjacent management areas not included in this survey are shown for reference: Lost Creek, HMA (magenta) and Antelope Hills (purple).

Figure 1A



Rock Springs
30
80
373
19.3 mi
© 2017 Google
Image Landsat / Copernicus
Google earth
41° 13.822' N 108° 33.123' W elev 7146 ft eye alt 84.70 mi

Figure 1B


189
89
789
191
30
80
373
Rock Springs
22.2 mi
© 2017 Google
Image Landsat / Copernicus
Google earth
42° 2.595' N 109° 12.990' W elev 7189 ft eye alt 96.41 mi